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LEVEL II

AN EXAMINATION OF ENERGY
CONSIDERATIONS IN THE
PRODUCT ACQUISITION PROCESS.

2LT. MICHAEL K. McCULLOUGH USAF

AFIT-LSSR-86-80

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AN EXAMINATION OF ENERGY CONSIDERATIONS IN THE PRODUCT ACQUISITION PROCESS

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Systems Management

By

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Second Lieutenant, USAF

December 1980

Approved for public release;
distribution unlimited

This thesis, written by

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has been accepted by the undersigned on behalf of the Faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS MANAGEMENT

DATE: 12 December 1980

Arthur L. King

COMMITTEE CHAIRMAN

TABLE OF CONTENTS

LIST OF FIGURES

Abstract

The conservation of energy through the acquisition process has become a significant concern to the Air Force in recent years. Therefore, an examination of energy considerations in product acquisition was conducted. The study constructs a taxonomy of energy costs incurred by the producer and owner of energy consuming products. The categories of the taxonomy include energy costs associated with product research and development, product production and construction, product operation and support, and product retirement and disposal. Examples of energy cost models are presented for each energy cost category listed above. These include facility energy consumption models, transportation energy use models, and production process optimization models. Examples of cost models to aid in the comparison of energy effectiveness among products in the source selection process are also presented and include scoring models, economic index and comparative models, and life cycle costing models. Thus, the study provides a basis by which the source selection authority can make a product acquisition/source selection decision with consideration of the products energy effectiveness.

CHAPTER I

INTRODUCTION

> Air Force Logistics Command must ensure that every opportunity to conserve . . . energy is seized. . . . All efforts short of sacrificing operational effectiveness should be taken to conserve energy [Air Force Logistics Command, 1979:11].

It can be predicted that by the end of 1980 the United States will use up to 90 quadrillion (10^{15}) British thermal units (Btu's) of energy (Dorf, 1978; McRae, et al, 1977; AFIT School of Civil Engineering, 1975; Tetra Tech, Inc., 1977). This is approximately one-third of the world's energy consumption. Of this amount, the Federal Government uses about 2.2 percent of the United States total; the Department of Defense (DoD) uses about 80 percent of the federal total (Air Force Logistics Command, 1979). A contracted research report by the Air Force Business Research Management Center (BRMC) shows where the Air Force stands in energy consumption (Rawl, et al, 1980):

> The United States Air Force accounts for approximately one-half of all DoD energy consumption or one (1) percent of the U.S. total. The goal of the Air Force in energy conservation is stated as "to insure energy effectiveness in its operations and equipment."

Thus, the Air Force could possibly use nearly 800 X 10^{12} Btu's of energy this year (Tetra Tech, Inc., 1977). This energy amount is an upper limit projection; however, the impact of this amount of energy is not insignificant to the world energy situation. Considering the phenomenal escalation of the cost of energy inputs in the past seven years, it is clear that the Air Force would benefit in cost savings if it acted decisively to reduce its energy consumption. The BRMC report states that $847 million has been allocated by the Air Force to projects for the conservation of energy over the next six years. These funds are primarily for facilities conservation and alternative fuels development (Rawl, et al, 1980).

A significant reduction of the energy needs of the United States can be achieved by the conservation of energy; anywhere from 10 to 40 percent has been realistically forecasted to be achievable over this decade (Dorf, 1978). Energy conservation can be realized in four areas:

- reduction or elimination of wastes;
- shifting to less energy-intensive processes;
- reduction of energy-consuming activities;
- and improving the efficiency of energy-consuming activities (Dorf, 1978).

To promote energy conservation in the Federal Government in the above areas, President Carter set specific energy goals in April 1977 to be met by the year 1985. They are to:

- reduce our annual energy demand growth to less than two percent;
- reduce our gasoline consumption by 10 percent;

- cut our petroleum imports to six million barrels per day;
- establish a one billion barrel crude oil reserve;
- increase coal production by two-thirds;
- insulate 90 percent of all American houses and all new buildings;
- and, to use solar energy in more than 2.5 million homes (Dorf, 1978; Kinder, et al, 1978; McRae, et al, 1977; Tetra Tech Inc., 1978).

Since the Federal Government is a significant user of energy in the United States, a policy to meet the above goals will provide an example of energy conservation to the private sector. Thus, the President issued Executive Order 12003 in July 1977 requiring each Federal Agency to:

- improve the agency's average fleet vehicular miles per gallon (MPG) annually on a set scale;
- reduce energy use per square foot by 45 percent in new federal buildings;
- reduce energy use per square foot, 20 percent by 1985 for existing federal buildings;
- develop a ten-year agency energy management plan to be updated annually;
- and, to report annually the agency's progress toward its goals.

One method to aid the Air Force in achieving the above requirements is to consider energy in the acquisition process. Considering that the Federal Government is the largest single purchaser of goods and services in the United States (Rawl, et al, 1980), a procedure to consider the energy costs can have a significant impact upon the use of energy by the Government.

Statement of the Problem

This thesis examines the following problem: What are the energy cost components associated with the design, production, operation, and disposal of products utilized by the Air Force and what are some examples of models that consider these components in the acquisition process of these products?

Statement of the Objectives

This thesis has two main objectives which are listed here:

1. To identify and examine the energy costs--
    a. That apply to the producer of goods or services for the Air Force,
    b. And that apply to the energy consuming products acquired by the Air Force.
2. To provide examples of available cost analysis models--
    a. That consider the energy consumption of the production facilities,
    b. That consider the energy costs associated with the production and distribution processes,

c. And that consider the energy costs incurred in the operation and disposal of the products.

Methodology

The thesis begins with a literature review that investigates Air Force policies established for the consideration of energy in product acquisition. The review includes a search for procedures that the decision maker can use in the source selection process as an aid in the consideration of energy. Where procedures are not established in the literature, examples of how "traditional" cost models can be used for energy consideration are presented.

To provide the decision maker with information to establish the criteria for these cost models, a taxonomy of energy costs that can be accounted for by the producer or user of energy consuming products is constructed. The breakdown of the energy costs is oriented around the four main cost catagories of a product - research and development, production, operation, and disposal.

This thesis is limited to reviewing models for use in a less-than-major acquisition. Thus, the models could be used by a purchasing officer to analyze the acquisition of vehicles, appliances, electric motors, air conditioners, and other general use type equipment that consumes some form of energy.

Overview of the Thesis

Chapter II of the thesis reviews the literature in two areas. First, an examination of the Air Force acquisition process is conducted. The policies requiring energy consideration in a source selection are reviewed. Second, thoughts on energy conservation through the government acquisition process are reviewed.

In Chapter III, a taxonomy of energy costs is developed for the producer and the product. For the producer, energy costs of the plant, transportation, and the production process are discussed. For the product, energy costs for the operation, support, and disposal or retirement are discussed.

Chapter IV presents examples of models applicable to considering the energy costs brought out in Chapter III. Cost models for the producer that consider the building energy use, transportation energy use, and production methods energy use are discussed. Also, examples of cost models for the product that consider energy in the acquisition, operation, and disposal or retirement stages are reviewed.

Chapter V provides an evaluation and conclusion from this study. Recommendations for further study are also presented in this chapter.

CHAPTER II

A REVIEW OF THE LITERATURE

> Purchasing by any group or individual affects energy consumption. But so great is the overall volume of government purchasing that it may be considered an implement of social change [Tether, 1977:5].

Much has been written in the past few years about the energy future of the United States and the Air Force. The U.S. Air Force Energy Plan (Tetra Tech, Inc., 1978) presents the concern of the Air Force for the development of a comprehensive energy management plan to control the consumption of energy in the future. The Plan states that the energy program of the Air Force must include all energy consuming activities; yet, the list of activities that is given does not include the acquisition process of the Air Force. This missing function is focused upon by Ivan Tether in his book Government Procurement and Operations. He states:

> For many reasons, including higher acquisition prices of energy-efficient items, lack of awareness, and bureaucratic tradition, many state and local purchasing authorities continue to buy goods and buildings that consume unnecessarily large amounts of energy. The aggregate of governmental energy consumption is thus much greater than required by the present level of operations. Reduction of this energy consumption requires a means of identifying the energy efficiency of prospective purchases and a means of selecting items that are relatively efficient.

This chapter will present a review of the literature regarding thoughts on energy conservation through the acquisition process.

The Source Selection Process

Air Force Regulation 70-15, "Source Selection Policy and Procedures", is the primary guidance for soliciting and evaluating offeror's proposals. The regulation also provides direction for selecting the sources for products procured by the Air Force. Paragraph 1-3, item (g), of this regulation defines the term "energy effectiveness". Energy effectiveness is the use of the least critical energy investment, the widest range of energy use capabilities, or the most efficient in terms of energy used (AFR 70-15, 1976). This definition provides a basis on which to establish criteria to consider energy in the acquisition process.

AFR 70-15 establishes policies the source selection authority (SSA) must follow in directing the source selection process, approving the selection plan, and for making the choice in the procurement source. The SSA is the primary decision maker in the acquisition process. Section 1-4, paragraph (a) states the SSA must be presented enough significant information on each of the offerors and their proposals to make an objective selection decision (emphasis added). Paragraph (f) of this same section requires that design-to-cost goals be established. It states:

> These goals must be clearly defined in the solicitation document and must be consistent with the

> total cost approach so as to encourage trade-off between acquisition cost and life-cycle cost (reliability, maintainability, [energy effectiveness], and other logistics cost).

Paragraph (i) of section 4:1 requires that evaluation criteria established for the use in the selection process be relevant and measurable, and they must be listed in order of importance. Thus, any selection model used by the SSA should be objective and should consider the importance of the criteria. This can be accomplished through a factor weighting system. Paragraph(n) of this same section states that the rating system may employ numerical scoring and weights or a descriptive color code in conjunction with narrative assessment (AFR 70-15, 1976).

Paragraph (k) of section 4:1 spells out this policy for energy consideration in the source selection process:

> The Source Selection process shall include a thorough evaluation of offeror(s) approach(es) to "Energy Effectiveness."

Guidance of how the SSA will make this evaluation is not presented. The literature provided no specific examples of how one should consider energy in the acquisition process. Instead, many examples of how one can consider a resource constraint are presented and, of course, these can be used with energy as a resource input. Because of the abundance of cost models that consider resource inputs, the construction of a specific model designed to consider only energy is a redundant task. It is more efficient in terms of cost and time for the decision maker to use existing models for his purposes. Chapter IV of this thesis examines examples of models that the SSA could use as an aid in the evaluation of "energy effectiveness".

Preparation of Evaluation Criteria

The previous section discusses Air Force policy establishing the requirement to consider energy in the source selection process. This section discusses how energy considerations can be established in a contract situation before the product is built. Although the information presented here is applicable to a major systems acquisition, the concept of early consideration is important. Therefore, a review of how one major acquisition organization prepares its evaluation criteria is reviewed here.

The evaluation criteria of a contract are defined at the time the selection plan is prepared, and become part of the plan and the request for proposal (RFP). Thus, the criteria for energy effectiveness are known to the offerors and they can attempt to comply. The evaluation criteria cover specific aspects of the product or service. They also cover the ability of the producer to furnish an acceptable product or service. The Aeronautical Systems Division (ASD) of the Air Force Systems Command (AFSC), for example, provides an evaluation criteria plan that is divided into four parts:

1. Introduction
2. General Considerations

3. General Basis for Contract Award

4. Specific Criteria (ASD, 1978).

The Introduction section of an evaluation criteria plan outlines the purpose of the program and describes in general terms the product or service desired. This section also describes any unusual evaluation criteria that are not normally used in other procurement selection methodologies (ASD, 1978).

The General Considerations section is short and provides information on the offeror's past performance, acceptance of contract terms, etc. Thus, the offeror knows how he stands with the Government.

The third section, General Basis for Contract Award is the most important. It provides the offeror information of what is of major importance in the program. It also establishes the relative importance of the major criteria. The importance of the acquisition cost factor is ranked along with the other factors, such as energy effectiveness. The Government reserves the right to award a contract at other than the low proposed price, based upon the relative importance of the cost factor (ASD, 1978).

The final section, Specific Criteria, is used to indicate the areas and items of major concern in the selection process. The specific criteria for energy considerations are provided here, either in terms of the acquisition or the life-cycle costs. These criteria can be segmented into two or more factors or subfactors (ASD, 1978).

There are other methods in preparing criteria for selection, yet they all are similar in the fact that they provide the prospective producers with an idea of what factors are important to the government. Consequently, it is important to the government and to the Air Force that an energy effectiveness criterion be written clearly. This will allow the producer to implement energy conservation methods in the design, production, and distribution of the products sold. The next section discusses literature concerning energy conservation.

Energy and its Conservation

It is generally agreed that conservation of energy is good, and that it should be attempted by everyone. Richard C. Dorf, in his book Energy, Resources, & Policy, states that the conservation of energy can cause a significant drop in the energy needs of the United States without a reduction in the standard of living. The strategies for energy conservation involve subsituting labor, capital, materials, knowledge, and management skills for the energy needed for production (Dorf, 1978). The last two elements--knowledge and management skills are the key elements for a conservation strategy involving product acquisition. The purchasing agent or SSA must decide upon a method (the management tools) necessary to aid him in the consideration of energy in the acquisition process.

One method available is to establish energy efficiency standards that must be met before the product can be authorized for purchase (Tether, 1977). When using this method, care must be taken in establishing the required level of efficiency. If the efficiency standard is set too low, the effort to establish control of energy consumption is wasted. A standard is designed to limit the field of choice to fewer products with higher efficiencies. If the standard is set too high, then the field becomes extremely limited, resulting in an unobtainable or very expensive product. Finally, if the standard is so high that only one producer can meet it, then the resulting absence of competition can make the price unnecessarily high and possibly violate a purchasing statute (Tether, 1977).

The standard, once set to an acceptable level, must be periodically reviewed to insure viability. Due to the increasing pace of technological advances, the standard has a built-in obsolescence (Tether, 1977). The AFLC Energy Master Plan requires that standards are to be reviewed quarterly (AFLC, 1979). This strategy is being used in Executive Order 12003. The order sets the average vehicular miles per gallon on a yearly basis (Kinder, 1978).

Another strategy involving management skills for energy conservation is to use a contract-awarding mechanism that will make trade-offs between acquisition price and energy efficiency.

> Contracts are nearly always awarded to the bidder who offers the lowest acquisition price, with little or no consideration of energy efficiency. Since the least expensive commodities are often the least efficient, money saved at the time of acquisition is usually insufficient to justify increased operating costs [Tether, 1977].

Another method in this strategy is to involve the producer in the responsibility of energy conservation along with the buyer. Tether states:

> It is necessary for governments to find a way to encourage manufacturers to improve the efficiency of their product during the life of the contract.

Therefore, Tether suggests a value incentive clause (VIC) to be added to certain fixed price supply contracts that exceed $100,000. The VIC encourages contractors to submit value change proposals (VCP's) over the span of the contract which result in a net savings to the government (Rawl, et al, 1979). The VIC method is a very promising strategy to reduce either the cost of performance of the contract or the cost of acquiring and operating the product. The only impediment to using this strategy is if the administrative costs of the contract become excessive or burdensome.

Summary

The literature brings out two general areas for energy conservation and effectiveness in source selection. One area involves the use of selection models that give the SSA a means for comparison. The other area suggests the use of incentives for the producer to use less energy-intensive processes and to produce more energy efficient products. The Chapter IV presents examples of models for both the producer and the SSA.

CHAPTER III

TAXONOMY OF ENERGY COSTS

> When accomplishing a . . . cost analysis, the analyst must develop a cost breakdown structure illustrating the numerous and varied segments of cost that are combined to provide the total system/ product cost [Blanchard, 1978:191].

When a decision has to be made, such as which particular make of a good will provide the best energy cost savings, the decision maker needs to have a firm basis on which to make the choice. Therefore, a discussion of where energy costs can be accounted for is necessary to use them as inputs to a viable decision analysis model. In the decision model, the significant costs are compared and are related as to the size of required investment and other factors, such as the benefits derived (Fisher, 1970; Horngren, 1977).

This chapter will examine the many areas where energy costs can be accounted for to provide information inputs to the decision model. The term costs refers to the "economic costs", signified by the expenditure of dollars such as on energy. This can include sunk and future costs. Sunk (past) costs are significant when assessing the actual cost of some activity or product and when determining if that activity or product was efficient (Blanchard, 1978). However, the most important costs for the decision maker are the future costs, for they represent meaningful alternatives between different products or processes.

The total cost concept will be used to insure that all of the relevant cost factors will be considered. The decision maker can easily overlook a significant element of cost unless the overall cost spectrum is addressed before selecting the specific elements of cost that are applicable to the problem at hand (Blanchard, 1978).

In this analysis, the specific cost factors are identified according to whether they are direct or indirect, variable or fixed, and recurring or nonrecurring.

Energy Costs of the Producer

The energy costs accrued by producers of goods for the Air Force fall into one of two major categories, either research and development (R & D) or production and construction costs. These catagories are general and may not apply to every producer, but they serve to classify most costs in a manufacturing environment. R & D costs will be discussed first.

Energy Costs in R & D

Not every producer of goods and services has an R & D program, but significant energy costs can be incurred by conducting research, development, test and evaluation (R & D). This section details the energy costs from R & D.

Product/Project Management. Throughout the life cycle of a project or product, the producer accumulates costs relating to the management of the product. These management activities include product planning, product research, product design, the management of the production, logistics management, and other applicable management functions (Blanchard, 1978; Horngren, 1977). These energy costs generally include the climate control and lighting of the building where the managers work, the fuel for company vehicles when they are used in conjunction with management activities, and the power for office machines used in support of the management. All of these energy costs are difficult to trace to a specific project or product unless the accounting system used by the producer is designed to do so. Thus, costs such as the lighting and climate control are generally accumulated in a cost pool and distributed over the entire operation (Horngren, 1977). However, some energy costs incurred by management can be directly applied to a specific product. The power used by a computer, for example. The data management section can keep track of the number of central processing unit (CPU) hours used in processing data for a project and use these hours as a base from which to allocate the energy (power) costs.

Product/Project Planning. Product planning includes market analyses, feasability studies, program proposals and planning, development of specifications, and financial planning (Blanchard, 1978). The energy costs incurred from product planning are generally the same as those mentioned above. They include building heating and lighting, power for office machines, and power for computer support. Generally, these costs are accumulated in an overhead cost pool.

Product/Project Research. There can be significant energy costs associated with product research. This category includes the costs associated with applied research, such as the laboratory support, manpower, materials, and facilities (Blanchard, 1978; Horngren, 1977). Generally, a laboratory facility is independent from other functions in a company, consequently all energy inputs can be monitored and the costs applied to the research laboratory alone. These can include electricity, natural gas, and any other form of energy used by the laboratory facility that is purchased from some supplier. Again, the costs might not be directly allocated to a particular product because of the accounting system used, but they can be isolated from the other functions of the producer, such as manufacturing.

Engineering Design. The next category of R & D is engineering design. This includes the conceptual, preliminary and detailed design efforts in the areas of electrical, mechanical, structural, and chemical engineering as well as human factors, safety, and functional analysis (Blanchard, 1978). The energy costs incurred by an engineering design section will be similar to the areas discussed before--building power and heat, etc. Again, these costs are generally accounted for as indirect.

However, there is one aspect of energy costs the engineering design section has control over that other sections do not. The designer has control to some extent of how the product will use energy. For example, a cost-efficiency tradeoff can be made in the manufacture of electric motors. The higher the quality and quantity of copper used in the motor's windings, the more efficient the motor will become (Fink, 1975). The motor will consume less power, but generally will cost more per unit. This control of alternative designs can affect the manufacturing energy consumption costs of the producer, but the design chosen most affects the user of the product. The energy efficiency standards set in the product design stages directly affects the energy consumption costs of the user. Thus, the alternative design energy efficiencies of the product are in reality alternative design energy costs, even though the costs will not be incurred by the producer.

Design Documentation. The next category of R & D costs is the design documentation. Here the preparation, printing, publication, distribution, and storage of all the data and engineering drawings of the product are considered (Blanchard, 1978). The energy costs associated with this category include the power for the machines that do the reproduction/printing, the energy used in the distribution, and, of course, the facilities energy costs for the printing shop and the storage location. Here, the energy used in printing/reproducing the documents can be directly allocated to the product or project involved, while the facilities energy costs are added to some standard overhead cost pool (Horngren, 1977). The allocation of energy costs involved in the distribution of the documents depends upon the accounting system used. If the distribution of the data takes it to locations other than the plant, the energy costs are generally considered in the shipping costs.

Product/Project Software. Another category of R & D costs is the product software costs. This includes the software development, modification, and production. Generally, the energy costs involved here are the power for the CPU time to develop and modify the software, and the facilities energy costs incurred to support this function. Usually, the CPU time can be directly accounted for while the facilities energy costs are indirectly accounted for.

Product Test and Evaluation. The final cost category under R & D is product test and evaluation. This includes the fabrication and assembly, test and evaluation of engineering prototypes, breadboards, and models. This category is probably the most significant of all of the R & D costs because of the nature of some product testing sequences. For example, electrical products are generally subjected to a "burn-in." This involves operating the product or device continuously for a specified period or until failure or destruction. Many products require a load bank consisting of high power resistors or high wattage light bulbs. Running a burn-in test consumes a large amount of power and generates considerable heat.

RESEARCH AND DEVELOPMENT ENERGY COSTS

PRODUCT/PROJECT MANAGEMENT	. facilities energy consumption . office machine energy consumption . transportation energy consumption
PRODUCT/PROJECT PLANNING	. facilities energy consumption . office machine/computer energy consumption
PRODUCT/PROJECT RESEARCH	. research project energy consumption . lab facilities energy consumption . research equipment/computer energy consumption
ENGINEERING DESIGN	. facilities energy consumption . office machine/computer energy consumption . alternative design energy considerations
DESIGN DOCUMENTATION	. printing/reproduction energy consumption . facilities energy consumption . transportation/shipping energy consumption
PRODUCT/PROJECT SOFTWARE	. computer energy consumption . facilities energy consumption
PRODUCT TEST AND EVALUATION	. test operation energy consumption . test equipment/computer energy consumption . facilities energy consumption

Fig 1. Energy Costs in R & D

Therefore, where test operations consume some form of energy, the energy costs can be accrued directly to the project or product. Additional costs for energy include the test facilities, energy costs, and the power costs of the test equipment.

Figure 1 shows a diagram of the R & D energy costs discussed above. The next section discusses energy costs incurred during the production stage.

Energy Costs in Production and Construction

The production and construction category of the producer includes the operations analysis, product manufacturing, new facilities construction, and initial logistics support of the product (Blanchard, 1978; Horngren, 1977). There are energy costs associated with each of these cost categories and these are discussed below.

Operations Analysis. The operations analysis aspect of production costs include all the initial and recurring costs associated with the initial engineering and sustaining engineering of manufacturing and construction. This includes the plant engineering which consists of the design of the manufacturing facilities, the storage facilities, the administrative facilities, including the plant utility inputs requirements. Hence, the energy needs are initially assessed in the plant engineering stage. The specifications of the manufacturing equipment are also assessed at this stage and they have a great bearing on the operational energy costs of the facility. The decisions made at the plant engineering stage reflect alternative or opportunity costs and these alternatives can affect the dollar costs that will be spent on energy by the producer for his facility.

Also in the operations analysis category are the energy costs associated with the manufacturing engineering. Here the process design, make-or-buy decisions, test and special equipment design, and man-machine functions are considered (Blanchard, 1978). As with the previous category, the decisions made here impact the overall energy consumption of the facility. There are many constraints that influence the process (manufacturing sequences) design, for example. Energy often is not considered as one of these constraints (Tether, 1977). The design of special and test equipment has an impact on energy consumption, as does the make-or-buy decision. The producer should consider purchasing instead of producing material that is highly energy-intensive in its manufacture, whenever the supplier has a more efficient process, if the cost is within reason. Some sort of cost-benefit study can be made. Energy should be among the factors considered when a make-or-buy decision is facing the producer (Dorf, 1978).

Methods engineering is also a member of the operations analysis category. The work methods, standards, and design of subassembly and assembly operations are considered here

(Blanchard, 1978). Energy consumption is affected by the decisions made concerning the operation of the manufacturing equipment. Often the most energy efficient method for the manufacturing operations is not the most efficient when considering time or human factors (Dorf, 1978). Production control is also considered here. The decision of the size of the production lot is generally based upon the economic feasibility. There is a point where production of a certain size lot is inefficient with respect to energy because the number of items produced does not justify "firing up the works," whereas a larger lot may be feasible (Chase and Acquilano, 1977; Horngren, 1977).

Manufacturing and Construction. The next major category under production and construction costs is the manufacturing cost category. Here, all of the recurring and nonrecurring costs of the production, test, and initial distribution of the product are accrued (Blanchard, 1978; Horngren, 1977). The energy costs involved include all the power (electrical, steam, etc.) used in the fabrication and assembly of the product along with the lighting and climate control of the manufacturing facility. The energy resources used in the initial distribution include the fuels for the trucks, trains, etc. as well as the facility energy costs of the warehouse/ distribution section of the manufacturing plant. The energy costs of any manufacturing rework can be considered in this category also.

Facilities Construction. The accounting systems of many producers are already designed to keep track of the costs of all the resource inputs used in the manufacture of their products (Horngren, 1977). Consequently, the task of accounting for the energy resources used is not as formidable as it may seem. This is true for the construction cost category as well. Here, all of the initial acquisition costs of the manufacturing facilities, user operational facilities, maintenance facilities, training facilities, and product warehouses are accumulated (Blanchard, 1978). The energy costs that apply represent alternative costs because the initial acquisition costs of the utilities (gas, electrical, heat, air conditioning, etc.) are considered here. Since a choice is made between the utility inputs for a piece of equipment (i.e. gas or electric furnaces), and between pieces of equipment of varying efficiencies, the energy use profile of the facility is affected. Some of the cost models derived in the next chapter can provide the decision maker with a way to consider the energy costs in these initial acquisitions.

Quality Control. Another category is the quality control (QC) cost. The energy cost considerations here reflect design costs. A manufacturing standard for energy efficiency is the primary example. The manufacturer will have to decide what type of QC measures and testing are necessary to maintain the energy efficiency standard. The QC process can be very costly, as a rigid standard has to be maintained. Additionally, the energy costs of the facility and the test equipment should be included.

PRODUCTION AND CONSTRUCTION ENERGY COSTS	
OPERATIONS ANALYSIS	. alternative facility design energy considerations . alternative processes energy considerations . alternative methods and production control energy considerations
MANUFACTURING AND PRODUCTION	. production process energy consumption . production facility energy consumption . production distribution energy consumption . facilities energy consumption
FACILITIES CONSTRUCTION	. construction process energy consumption . alternative facility energy source considerations . alternative initial equipment acquisition energy considerations
QUALITY CONTROL	. energy efficiency standards consideration . facilities energy consumption . test equipment/computer energy consumption
INITIAL LOGISTICS SUPPORT	. transportation/shipping energy consumption . test/support equipment energy consumption . facilities energy consumption

Fig 2. Energy Costs in Production and Construction

Initial Logistics Support. The final cost category under production and construction costs is initial logistics support. This includes the initial customer service, initial supply support, initial test and support equipment, initial personnel training, and initial training equipment (Blanchard, 1978). The energy costs in this category are primarily transportation costs (i.e. the fuels necessary for the transportation). The transportation energy is necessary for the manufacturer's representative personnel to travel to the user for the installation, calibration, and maintenance of the product when these services are required.

Figure 2 summarizes the energy costs that can be considered by the producer in the production and construction cost category. Figures 1 and 2 together summarize the energy costs the producer can account for in the operation of his business. The second half of this chapter reviews the energy costs attributable to the product and its use.

Energy Costs of the Product

The energy costs of products incurred by the user involve more than just the energy consumed in operating them. All of the energy used in the support and maintenance of the product or system needs to be considered. Many times, the maintenance or repair of a particular piece of equipment uses more energy than the equipment itself consumes (Dorf, 1978). The following sections will detail the areas in which energy can be accounted for in the operations of the product by the user. The first cost area discusses energy costs for the operation and support of the product.

System/Product Operations

The primary category for considering energy costs of the product is product operations. Here, all of the costs associated with the operation, but not maintenance, of a system or product are considered (Blanchard, 1978). The energy costs are obvious; the energy consumed by operating the product or system is the cost to the user. Accounting for these costs is easy if direct metering of the energy resource used is available. If not, a base for allocation can be derived from the product's known standard energy consumption rate (such as miles-per-gallon for vehicles or watts for electrical products). Where a facility is required to house the product, then the energy costs of the facility are to be considered also. An example of this is the lighting on a protective building that houses instrument landing systems (ILS) equipment at airfields.

Sustaining Logistics Support

The other category is the sustaining logistics support area. Here, all of the costs associated with the maintenance and support of the product or system over its life cycle are considered (Blanchard, 1978). The energy costs include energy consumed in customer service, all of the energy consumed by test equipment, machines used in the maintenance/repair of the product, and any transportation use. The same energy costs can be accounted for in unscheduled maintenance, preventative maintenance, and test equipment operation. The user will also bear energy costs associated with supply support (warehouse facilities energy consumption), transportation of the product, and modification of the product. Figure 3 details the energy cost breakout in the operation and support category.

OPERATION AND SUPPORT ENERGY COSTS

SYSTEM/PRODUCT OPERATIONS

- product operation energy consumption
- facility energy consumption
- supporting equipment energy consumption

SUSTAINING LOGISTICS SUPPORT

- customer service energy consumption
- test/support equipment energy consumption
- maintenance facility energy consumption
- warehouse facility energy consumption
- transportation energy consumption
- product modification energy consumption

Fig 3. Energy Costs in Operation and Support

Energy Costs in Product Retirement and Disposal

The second cost area of the user of the product involves the costs for retirement and disposal of the product. Here, all of the costs for the phase-out and disposal of the product are accrued (Blanchard, 1978). The energy costs are both direct and indirect. The actual disposal process will consume energy by using machines and power tools in the disassembly of the product, vehicles for the transportation of the salvage to the dump site, or energy if it is destroyed in a furnace or reprocessed in some way. There are alternative energy costs involved in the disposal decision, also.

RETIREMENT AND DISPOSAL ENERGY COSTS

PRODUCT/SYSTEM RETIREMENT

- alternative decision energy considerations
- storage facility energy consumption
- transportation energy consumption
- removal process energy consumption

PRODUCT/SYSTEM DISPOSAL

- product removal/disassembly energy consumption
- transportation energy consumption
- disposal process energy consumption
- facilities energy consumption

Fig 4. Energy Costs in Retirement and Disposal

These come from the consideration of what product will replace the existing one. If the new product has the same or worse energy efficiency, then the disposal decision is complicated. Figure 4 shows the breakout of the energy costs for retirement and disposal.

Summary

This chapter has presented a general cost breakdown structure for considering energy in the manufacture and use of a product. Figures 1 through 4 detail these costs. As can be seen by these figures, the elements under each of the major cost categories are not mutually exclusive. Some of them, such as facility energy consumption, are common throughout. Hence, cost models to aid the decision maker in decisions concerning energy are designed to take these common features into account. The next chapter provides examples of some of these models.

After reviewing the four figures presented in this chapter, it is clear that energy is essential and is used in every aspect of manufacture and operation of the product. Thus, methods to account for energy consumption and to provide for its control are necessary to management. The management tools currently available to the decision maker can provide this accounting and control.

CHAPTER IV

MODELS FOR CONSIDERING ENERGY COSTS

> Some form of price or cost analysis is required for every purchase. The method and scope of analysis required are dictated by the dollar amount and circumstances attending each purchase [Lee and Dobler, 1977].

For the producer, there are many models available for the analysis of the energy use of the facilities, to provide for an efficient transportation scheme, and to aid in the planning of the production process. The first section of this chapter will present examples of some of them. For the product, there are also many models available to compare one or more factors for a source decision among two or more producers. The factor of primary concern is, of course, energy effectiveness.

Cost Models for the Producer

In Chapter III, the taxonomy of energy costs for the producer showed that there tended to be three general "groupings" of the costs. These are the facility energy costs, transportation energy costs, and production process energy costs. This section will discuss models in each of these groups.

Facility Energy Consumption Models

The majority of models available that analyze the energy use of buildings are complex. Consequently, the models are generally analyzed in computer programs. These programs are generally similar in structure and are usually divided into four main segments. The first part considers each thermal zone in a building and calculates the space heating or cooling loads necessary to maintain the specified interior climate conditions. The model input information needed includes details of the building design, weather conditions, and interior occupancy and equipment use schedules.

The second part of the program usually simulates the heating, ventilation, and air conditioning (HVAC) air-side system which is controlled to satisfy the space loads already calculated. The information needed for input to the model consists of the type of system, performance characteristics, and operation and control procedures. Many existing programs contain generic simulations of the most common HVAC systems, thus the user need only state which system is to be simulated.

The next segment of the program simulates primary equipment such as chillers, boilers, and on-site power generation, and then computes the energy resource requirements necessary for the equipment to satisfy the system energy requirements of the building's HVAC zones. The information input requirements consist of the specification of performance characteristics and actual thermal configuration of the equipment.

The fourth part of the program is generally an economic analysis of some type. Here the energy costs are accounted for from the ownership and operation of the plant. The information needed is the cost of the building equipment and the cost of the energy resource used (AFIT School of Civil Engineering, 1975). The following "canned" computer programs are available to aid the producer in evaluating the energy efficiency of his plant. These programs are tested and are operational.

The Alternate Choice Comparison for Energy Systems Selection (AXCESS) program provides the simultaneous comparison of up to six alternate methods for meeting the energy requirements of a facility. The program is versatile enough to be used at any stage of a building's design or construction. It offers a complete energy analysis of one or more buildings including load determination, air-side system simulations, plant equipment simulations, and yearly operating costs. Input requirements for the program include the local weather data, a description of the building project, base load profiles, design heating and cooling load, space type information, zone data, HVAC system description, and output desired from the program run. The program outputs are many and include the energy consumption and demand at each of up to 36 meters of the energy resource inputs for each of the alternate systems. AXCESS is limited to calculating only up to 180 energy zones per run. Also, only a maximum of six schemes or combinations of primary and secondary systems are possible, with each scheme having up to 12 different types of fan systems and six primary systems. The program is available through participating utilities, time sharing systems, source or object code decks (which may be purchased), and as a service from a participating consulting firm. Further information on AXCESS can be obtained from:

E. S. Douglass
Edison Electric Institute
90 Park Avenue
New York, New York 10017

The Building Load Analysis and System Thermodynamics Program (BLAST) was developed by the U.S. Army Construction Engineering Research Laboratory (CERL) for the U.S. Air Force. The program contains three simulation segments. These are building loads, air-side systems, and building equipment use simulations. BLAST contains a well developed user-oriented input language with a preprocessor for inputing and checking data. It also contains provisions for establishing a library containing building materials and component properties, equipment characteristics, and various equipment schedules and system control procedures. BLAST is the fastest running of all of the programs using a similar analysis methodology.

The program input is highly user-oriented and varies in the amount of detail that has to be provided. A minimum of inputs are possible since the program provides common default values. The outputs from BLAST include data echo, diagnostic messages, assigned default values to override erroneous input data, system configurations description, and equipment energy consumption analysis (monthly or yearly). There is comprehensive documentation available, and the program can be used on CDC 6000/7000 series computers without modification. The program is written in CDC FORTRAN Extended Version 4. Further information can be obtained from:

F. Beason
Air Force Civil Engineering Center (AFCEC)
Tyndal Air Force Base, Florida 32403

The Energy Conservation Utilizing Better Engineering (ECUBE) program series provides design point calculation of peak thermal and electrical loads for hourly, monthly, and yearly estimates of the facility energy requirements. Various systems to meet these requirements are then analyzed and compared. The ECUBE series consists of three separate programs: (1) Energy Requirements Program, (2) Equipment selection and Energy Consumption Program, and (3) Economic comparison Program. The input requirements for ECUBE are the maximum value and hourly percentage profiles for internal heat gain of the facility, electrical load, and process load. Also needed are the transmission and outside air loads as a function of ambient temperature, maximum solar load on the building, hourly weather data, heating value of the fuel used, and the part-load equipment performance characteristics. Also, the capital cost differential for alternate systems, salvage values, and maintenance costs are needed. The outputs from ECUBE include the monthly, yearly, and peak energy requirements along with the yearly fuel requirements for alternate systems. Cash flow and discounted rate of return on alternative investments are also provided. The program can be utilized through Control Data Corporation's Cybernet time sharing network or through a leasing agreement. The contact for more information for ECUBE is:

Mr. K. T. Cuccinelli
Manager -- Energy Systems
American Gas Association
1515 Wilson Boulevard
Arlington, Virginia 22209

The Meriwether Energy Systems Analysis Series (ESAS) is a library of computer program models which can determine the annual consumption of energy of various types of systems and equipment for a typical year of operation, and determine the relationship between these energy costs and other operating costs. The basic analysis series of programs include the Energy Requirements Estimate (ERE) which calculates the thermal and electrical loads of the facility on an hour-by-hour basis, the Equipment Energy Consumption (EEC) which simulates the operation of the equipment in the plant, and the Economic Comparison of Systems (ECS) which calculates the total acquisition and operating costs of each system. ESAS is a proprietary system which offers a complete energy analysis of one or more buildings from load determination to energy requirements simulations of equipment to economic comparisons of alternative system designs. ESAS requires engineering design data, a system design and operation description, weather data, the utility rate structure, and the acquisition and operating cost data for inputs to various programs in the series. The outputs provide monthly and yearly demand and consumption for the systems and equipment, the monthly and yearly utility costs, and life cycle cost and cash flow analysis. No algorithm has ever been published because the program is proprietary. A user's manual is available only from the program owner and has complete instructions. Further information is available from:

Ross F. Meriwether and Associates, Inc.
1600 N. E. Loop 410
San Antonio, Texas 78209

The McDonnell Douglas Automation Company's Annual Consumption of Energy Program (MACE) provides facility energy analysis using methods recommended by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). The load calculation section uses methods outlined in "Proposed Procedures for Determining Heating and Cooling

Loads for Energy Calculations", ASHRAE, 1969. The component and system simulation section uses procedures outlined in "Proposed Procedures for Simulating the Performance of Components and Systems for Energy Calculations", ASHRAE, 1969. The economic section of MACE uses procedures incorporating the local utility rate structure. MACE also utilizes the local weather conditions in its analysis. The program inputs require data from the local weather conditions, building and system descriptions, energy rate structures, master time schedules, and appropriate loads. The outputs provided include calculations for hourly space and building loads, estimated electrical power usage, estimated fuel consumption, and all of the energy costs on an hourly basis with monthly and yearly totals. The program uses FORTRAN IV for IBM system 360 computers. Further information on MACE can be obtained from:

Mr. Charles E. Whitman
Engineering Services
McDonnell Douglas Automation Company
Box 516
St. Louis, Missouri 63166

NASA's Energy Cost Analysis Program (NECAP) also follows the procedures outlined in ASHRAE's "Procedures for Determining Heating and Cooling Loads for Energy Calculation" to estimate the energy requirements for buildings. NECAP is a set of programs which include a response factor program, a data verification program, a thermal loads analysis program, a variable temperature program, a system and equipment simulation program, and an owning and operating cost program. The series is an extension of the Energy Utilization Program developed for the U.S. Postal Service. It is extensively modified to improve its usability. NECAP input requirements include the building parameters, building coordinate system, azimuth angle, surface description and tilt angle, data on the floor, ceiling, and furnighings, space descriptions, thermostat schedules, design information of the energy distribution system, and cost information. The output provides response factors, summary of design-day weather, space and building loads, surface shadow pictures and shadow calculations, recommended space heat extraction and addition rates, variable temperature loads, zone airflows, summary of loads not met, equipment capacity summary, and monthly and yearly energy summary. The program language is FORTRAN IV and can run on the CDC 6400 and 6600 computers. NECAP information is available from:

COSMIC
Suite 112
Barrow Hall
University of Georgia
Athens, Georgia 30602

An extension of NECAP is the GARD Program for Facility/HVAC Design and Energy Analysis (SCOUT). SCOUT follows the design procedures from the two ASHRAE publications previously mentioned. The input requirements are the same as NECAP, but the program outputs include space and building peak loads broken out into components, optional surface and space response factors, optional design-day weather summary, optional shadow pictures and calculations, recommended space air flows and heat extraction and addition rates, equipment capacity summary, summary of space and system loads not met, monthly and yearly energy summary by system and building, minimum and maximum space temperatures, and a payback period comparison of alternatives. SCOUT is written in FORTRAN IV and can be run on the CDC 6400 and 6600, IBM 360 and 370, Univac 1108 and Univac Spectra 70/46. Further information on this program is available from:

GARD, Inc.
7449 N. Natchez Avenue
Niles, Illinois 60648
Attn: SCOUT Support Team

The final energy analysis program discussed here is the Trane Air Conditioning Economics program (TRACE). The TRACE program calculates peak and hourly zone loads based on coincident hourly climatic information for temperature, solar radiation, wind, and humidity of typical days in the year representing seasonal variations. The average days are compiled based upon the ten most recent years of U.S. Weather Bureau data. The design phase receives the input from the load phase as well as system type information and zone design information, and calculates supply air quantities and temperatures. The system simulation phase utilizes hourly zone loads and calculates return air quantities and temperatures and accounts for system loads. The equipment simulation phase takes the hourly output from the system simulation phase and calculates the annual energy consumption based on part-load performance data which is available on tape. The economic phase does an economic comparison of the various design alternatives based on input consisting of energy consumption data, utility rate structures, and expected installation and maintenance costs. TRACE requires the building, system, and equipment descriptions and economic factors as inputs. The outputs available include peak building loads, building and equipment yearly and monthly energy consumption, and economic comparison of life-cycle cost for up to four alternatives in one computer run. The program source code is proprietary, but the program may be utilized through Trane or through time-sharing systems. Information on TRACE is available from:

Applications Engineering
The Trane Company
3600 Pammel Creek Road
LaCrosse, Wisconsin 45601

The choice of which of the above mentioned programs to use will be dependent on the information desired. The serious producer could obtain information from all of the sources so as to determine the program package that is best able to analyze the manufacturing plant that he is interested in. Such an interest may be beneficial to the producer, especially if the contract provides for a value incentive clause requiring plant energy efficiency.

Energy Cost Models for Transportation

The taxonomy of energy costs for the producer showed that energy consumed for transportation is a major energy cost area. One example of a model used to consider energy in distribution is the transportation algorithm. The algorithm is a specialized case of the simplex method of linear programming. The decision maker can utilize this method to minimize the energy costs involved in transporting n homogeneous units to m locations. This model can also be used to maximize the energy efficiency of moving n homogeneous units to m locations. The units may be raw materials, finished products, or they may be the technical data for the products. In general, there are three steps involved in the operation of the algorithm.

The initial step is to set up the transportation algorithm matrix. Figure 5 shows a typical transportation matrix. The top of the matrix lists the destinations of the units, the left column lists the starting points. In the

From \ To	Q	R	S	T	Supply
A	C_{11}	C_{21}	C_{31}	C_{41}	x_1
B					x_2
C					x_3
D	C_{14}			C_{44}	x_4
Demand	y_1	y_2	y_3	y_4	Σy Σy

Fig 5. The Transportation Matrix

far right hand column the available supply at the production plant is shown and the demand at the destination is listed in the bottom row. Within the cells in the matrix the cost for shipping one unit from the source to the destination is listed. If there is an excess supply or demand, an extra row or an extra column is added to the matrix to represent an additional factory or an additional warehouse. This "dummy" row or column will have an amount of supply equal to the difference between the row and column totals. Thus, the total supply will always equal the total demand (Budnick, et al, 1977; Chase and Aquilano, 1977). For consideration of energy costs in transportation, then, the above matrix cost cells would have the energy consumption cost associated with moving one unit from A to S, for example. That energy cost would be C_{31}. This example shows only four sources and four destinations. The number of sources or destinations is not restricted to any number.

The second step is to make the initial allocations of source supplies to destination demands. There are several methods of doing this, but two are the most common -- the northwest-corner method and Vogel's approximation method (VAM). The northwest corner method entails assigning as much as possible of the supply to the cells in the first row starting with the upper left-hand, or northwest corner, cell. This procedure is repeated for each succeeding row until all of the row and column requirements are met. This method does not consider the costs of each cell in this initial step (Budnick et al, 1977; Chase and Aquilano, 1977). The VAM method utilizes the cost information to make the initial allocation, and consequently provides an optimum or near optimum initial solution. The VAM procedure is:

1. Find and list the difference in costs between the two lowest cost cells for each row and column.

2. Pick the largest difference of a row or column.

3. Assign the maximum possible amount to the lowest cost cell in the chosen row or column. This allocation will satisfy a row or column requirement. A tie is handled by allocating to the lowest cell in any of the tied rows or columns. Tied cell costs mean that the allocation can be given to one of them arbitrarily.

4. Repeat 1 through 3, eliminating the row or columns that have been satisified from consideration. Repeat the procedure until the supply and demand requirements are met (Chase and Aquilano, 1977).

The final stage is to develop an optimal solution (lowest energy cost or highest energy efficiency). This involves evaluating each unused cell in the matrix to determine whether a shift of supply into it is better from a total cost standpoint. If it is, the shift is made and the step is repeated (Budnick, et al, 1977). The optimal solution will give the producer the best method for supply or product distribution with respect to transportation energy use.

If the production process of some products requires that subassemblies be transported to another location for further work or assembly, then another analysis method needs to be used to consider the transportation energy use. An example of a technique to use in this case is dynamic programming. Dynamic programming breaks down a multistage process into subparts or single stages. When using this technique for transportation energy consideration, the stages represent the manufacturing plants required in the production process of the product assembly. Then, the dynamic programming model allows for decisions to be made one at a time, or recursively, at each stage, according to the required optimization objective; in this case, to minimize transportation energy costs. Finally, the results at each stage are combined to provide an overall optimal solution with respect to the optimization objective (Budnick, et al, 1977). A specific example of the use of this technique will not be presented here. Many sources are available that provide specific information on dynamic programming.

There are many other transportation models available for optimizing costs. A review of texts for operations research or production management will provide more information on these techniques.

Production Process Models for the Producer

Many models and analysis techniques are available to aid the producer in establishing a production process. For example, there is a whole class of heuristic programs in this area (Budnick, *et al*, 1977). Variations of the Program Evaluation and Review Technique (PERT) also can provide assistance in planning, scheduling, and controlling production processes (Chase and Aquilano, 1977).

As an example, if the production plant is considered a randomized job shop, then there are three computer models available for optimizing the production process. These are discussed below.

The Automated Layout Design Program (ALDEP) can provide the producer with a layout matrix with departments and aisles drawn out by the computer plotter. The program can layout a building of up to three floors. The required inputs for ALDEP include the size and number of each department to be located in the facility, the description of the building dimensions (exterior and interior), a preference table giving relative department location preferences, and the control cards to activate subroutines. The outputs include the layout matrix with aisles and departments drawn in and a preference score for each layout. The program can handle up to 63 departments (Chase and Aquilano, 1977).

The Computerized Relationship Layout Planning (CORELAP) provides the user with near optimum solutions which uses little computer time. The program input requirements include a relationship chart that lists relative department location preferences, a building width-length ratio, departmental area restrictions, and the size of the area partition per department. The outputs include a numerical layout matrix printout with digital plotting also available. The program can handle up to 70 departments with over 1000 interdepartmental relationships (chase and Aquilano, 1977).

The Computerized Relative Allocation of Facilities Technique (CRAFT) provides a cost analysis of each layout computed. The program inputs required are the initial block layout, an interdepartmental flow load matrix, and the material handling cost matrix. The outputs include a block layout to conform to the facility dimensions and the cost of each solution leading up to the final solution. The program can handle up to 40 departments. CRAFT is the only one of the three that can provide an immediate cost estimation of the layout solution. If the material handling cost matrix is entered in terms of energy costs then the solution will give the best overall layout in terms of the lowest energy cost for the process design.

The producer will have no problem in finding techniques that apply to his particular plant setup that aid in optimizing the production process. A review of the literature can provide a wealth of information on these techniques.

Cost Models for the Product

The previous section showed examples of models available to the producer for considering energy consumption in three main areas. Many of the models are computer programs, with several available that can be worked by hand. For the case of energy consideration of products, available models are generally of the "hand" type. This less complicated level of analysis provides a purchasing officer a means by which to analyze any product acquisition without the need for computer support. Examples of these models are discussed below.

The term "cost model" has several varied meaning depending upon the context. However, cost models are all related in the sense that they all serve as an integrating device to facilitate the analytical process and to aid in the decision process (Fisher, 1970). The cost models discussed in this section serve as methods to form a basis for comparison between different products with respect to energy effectiveness. As mentioned earlier, the models allow the decision maker a rapid, hand worked solution to the question of which product has the least energy costs.

Scoring Models

Scoring models are a method to compute an overall numerical score based on ratings assigned to each product considered for each decision criterion. They are designed to operate with subjective and objective criterion. Thus, products will be scored on how well they meet the energy cost criteria established for the model (Allan and Transmeier, 1980). Because of the many different ways in which a product can use energy or affect energy use in the operational environment, specific criteria will not be discussed here. The decision maker can tailor certain criteria based upon the type of product to be purchased.

In general, a scoring model to consider the energy effectiveness of products could contain the following criteria: Product energy efficiency, product energy source, acquisition cost, product life, and disposal cost. Not all of these criteria will apply to a particular product. Some products will require additional criteria to allow a more complete consideration of the energy effectiveness. The ones listed here are the general "all-purpose" criteria, and each is discussed below.

The product energy efficiency criterion deals directly with the rated efficiency or the rated energy consumption of the product. The score given on this criterion reflects how acceptable the energy efficiency or the energy consumption rate is to the decision maker (usually the SSA). An acceptable level of energy efficiency would show a midrange score, while the best efficiency or lowest consumption rate would be deserving of the highest score.

The product energy source criterion deals with the primary and any alternative energy sources necessary to use the product. The score given here reflects the desirability of one energy source input over another due to the costs of source or the availability of supply. Each of these factors can be scored separately and the scores combined in some manner. A high criterion score here would reflect a low cost source with almost unlimited availability, while a low score would show an undesirable source due to high costs (or expected high costs) or restricted availability, or both.

The acquisition cost criterion deals with the fact that higher energy efficiencies many times means higher acquisition cost (Dorf, 1978). A high score here would indicate the willingness of the purchaser to pay that extra cost. The low score would indicate the extra cost is too high to have an acceptable pay-back period.

The process of replacing or installing equipment involves energy use (Dorf, 1978). The product life criterion permits analysis of this fact. Additionally, this criterion deals with the expected energy costs for maintaining the product. Again, each of these factors can be scored individually, and the scores combined to provide a composite score. A high score would indicate an acceptable life with low expected maintenance costs while a low score would indicate a high expected replacement rate or high energy costs associated with the product maintenance, or both.

There are energy costs associated with the retirement or disposal of the product after the end of its useful life (Dorf, 1978). The disposal cost criterion permits analysis of this fact. The score given here would indicate the expected level of the costs involved. Thus, a high score would reflect a low expected energy cost in retirement or disposal.

The scores produced by the criteria discussed are combined by the model to produce an overall index number. The product with the highest index number is the best in regard to energy effectiveness. The criterion scores can be combined in different ways to produce the overall index. A criterion that has two or more factors that are independently scored can be given its overall score in one of three ways: The individual scores can be added together; multiplied together; or each multiplied by a weighting factor and then summed. If only a few of the criteria have two or more factors, then the factors are generally weighted and summed so that the summed score is no higher than the highest number used in the scoring system. Otherwise, if all of the criteria have the same number of factors each, the factor scores are either added or multiplied to give the overall criterion score. One preferred method is to multiply the factor scored so as to give an increased range of overall index numbers (Moore and Baker, 1969).

The criteria scores can then be summed, or multiplied by weight factors. The second method is sometimes preferrable since the weight factors provide a heirarchy of criteria giving the most important criterion the highest weight (Moore and Baker, 1969). The weighted scores are then summed to give the overall index. This procedure is repeated for every product under consideration. The product with the highest index score is the recommended product for selection with reference to the model criteria.

The scoring model should not be too elaborate or expensive to utilize (Allan and Transmeier, 1980). It should be easy to understand and convenient to use by the scorer. Problems in using a scoring model include the tendency for the scoring criteria to be too subjective by design. Since the rating of each criteria by the scorer is judgmental, an objective rating is sometimes difficult to achieve. Also, the scoring model is many times better suited as a screening device rather than the final selection device. After the field of choices is narrowed down by the scoring model, other analysis techniques can be used to make the final decision.

Economic Index and Comparative Models

This class of models provides a comparison of the products based upon economic considerations. Here, the determining factor might be a cost to benefit ratio, a percentage price differential, or an efficiency ratio based on the number of years required for the payback (Tether, 1977).

The cost-benefit ratio model could use the energy efficiency rating (EER) as the basis for determining the benefit derived. Thus, the model will compare the acquisition cost and the EER of each product against the other. This can easily be done by dividing the cost by the EER to achieve a raw ratio. Since EER's are determined as Btu's per watt, the lower the EER, the worse the energy efficiency of the product. Therefore, the product withthe lowest cost-benefit ratio provides the best investment. There are problems with such a rating system, however. If the product cost for one unit is double that of another and the EER is also double, the cost-benefit model will return the same numerical ratio. This can be overcome by realizing that this problem exists, and making sure that the ratio number is fully understood before a purchase is made. A weighting can also be applied to either the cost or the EER before the ratio is calculated to avert this problem. This model, as with the scoring model should be used primarily for screening the product field instead of making the final source determination.

The percentage price differential model requires the establishment of a sliding scale of the percentage price differentials that will be granted for specified increases in efficiency. The problem with this model is the setting of the ratios of the price percentages to various increments of energy efficiency improvements. Once the scale is established, the model provides trade-offs between purchase price and energy efficiency.

Energy Efficiency Increase (%):	1	5	10	15	20	25	30	35	40	45	50+
Percentage Price Differential (%):	1.5	3	5	7	10	13	20	23	27	31	35

Fig 6. Percentage Price Differentials (Tether, 1977)

The best way to describe this model is to provide an example. Given the arbitrary scale above in Figure 6, the percentage price differentials (PPDs) are used to evaluate a hypothetical acquisition example of electric motors for conveyor belt use in warehouse facilities. Figure 7 shows the results of using PPDs as a decision aid.

Motor	EER (Btu/Watt)	Energy Efficiency Increase (%)	Acquisition Cost ($)	Cost Increase ($)	PPD (%)	PPD Cost ($)
A	7	-	200	-	-	200
B	7	0	220	20	0	220
C	9	28.6	280	80	13	243.6
D	11	57.1	300	100	35	195.0
E	12	71.4	340	140	35	221

Fig 7. An Example of PPD Cost Analysis (Tether, 1977)

If the motor purchase was based upon acquisition cost alone, motor A would be purchased. If the purchase was based on the highest energy efficiency, then motor E would be purchased. However, with PPDs, motor D is determined to be the winner since it earned a $105 price differential, or 35 percent of the $300 acquisition price. This graphically points out the fact that the evaluation method has a significant impact upon the final decision, thus, the importance of clearly establishing the evaluation model beforehand.

EER	Watts	Annual Energy Costs ($)	Annual Energy Cost Savings as Compared to A's Energy Use ($)	Acquisition Cost Increase Over A ($)	Payback Period (years)
A 7	1,429	85.74	-	-	-
B 7	1,429	85.74	0	20	none
C 9	1,111	66.66	19.08	80	4.2
D 11	909	54.54	31.20	100	3.2
E 12	833	49.98	35.76	140	3.9

Fig 8. An Example of Payback Period (Tether, 1977)

A model based upon the number of years to complete the payback of acquiring the more efficient system over the cheapest one provides another method of analysis. If we assume each of the motors in Figure 7 were rated at 10,000 Btu consumption then a payback chart can be constructed. Figure 8 shows the payback period for each motor assuming 1000 hours of operation per year and a cost of six cents per KW hour. Again, motor D would be chosen since it provides the shortest payback period with respect to motor A, which would have been chosen because it had the lowest acquisition cost.

Thus, the PPD method of cost comparison provides a process by which the decision maker can follow to analyze a group of products to determine the product that gives the best tradeoff between the acquisition price and the energy efficiency. There are other methods available that consider a cost-efficiency tradeoff. One of these methods is the Life Cycle Costing (LCC) method discussed below.

Life Cycle Costing Models

Life Cycle Costing is a procurement technique that considers the costs associated with operation, maintenance, and support of products along with the acquisition price. LCC is a very promising technique for the consideration of energy use of products since energy expenditures constitute a large portion of the cost of ownership to the user (Tether, 1977).

Life Cycle Costing provides a means for the purchasing agency to be aware of the expected costs of ownership before a purchase is made and funds are expended. Total LCC requires that contracts be awarded on the basis of the lowest expected costs of ownership rather than the lowest acquisition price (Rawl, et al, 1979).

The LCC process has seven steps the user needs to follow:

1. Identify all of the costs to be incurred from owning and operating the product (including the initial acquisition cost and the cost of using the LCC analysis technique),

2. Determine the useful life of the product,

3. Estimate the salvage value for the product at the end of its useful life,

4. Discount all of the costs and the salvage value to their present value,

5. Subtract the salvage value from the cost of the product and divide the result by the estimated number of years of useful life. This gives the average annual cost of ownership,

6. Compare the average annual cost of ownership of each product under consideration,

7. Buy the least costly item show by LCC (Tether, 1977).

This process is tedious and cannot always be justified on small purchases. The BRMC report suggests a simplified formula to facilitate a more practical analysis. This formula is stated as:

$$A = B + C \times E \times L$$

where: A = Life Cycle Cost

B = Bid price per item

C = Energy consumption per unit of operation

E = Unit cost of energy

L = Expected life of the Item (Rawl, *et al*, 1979).

The formula is easy to use and to obtain data for. It can be applied at any level of size of purchase, within limits. Such a simple model would not be applicable to a major weapons system acquisition. This technique assures that the Air Force makes the choice of most energy-cost effective product. The simple model can be used for both screening products for acquisition and making the final source determination for the eventual purchase. The more complex model, which is often computerized, can truly be used for any purchase decision. The cost inputs to the models can include all of the costs mentioned in Chapter III. Thus, a thorough analysis is assured.

Summary

Chapter IV presented some examples of the many models available for use to consider energy in the many stages of a product's life, from manufacture to disposal. The cost models available to the producer vary in complexity from a simple hand analysis technique to a complex computer library of programs. The choice of which to use depends upon the magnitude of the analysis and the objective of doing such an analysis. The producer should have no problem in finding a model that best fits his situation.

Similarly, models that point out the best product by considering the energy costs of acquiring that product range from simple hand models to computer programs. The decision maker can choose the one that best fits his need. Since the

Life Cycle Costing technique is gaining favor in every level of government (Blanchard, 1978; Tether, 1977), the decision maker may wish to consider using it. LCC can be tailored to fit any need, whether considering energy costs, maintenance costs, or other product operation costs.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

> The development of quantitative techniques outstripped their range of likely application. That is, though models were sound in theory, the problems associated with implementing them (incomplete or inaccurate data, extensive time to set problems in the appropriate form, etc.) often exceeded the benefits derived from their use [Chase and Aquilano, 1977:691].

Basically, this thesis attempts to provide general information about the nature of energy costs in a source selection decision and how to consider dealing with them. The Air Force Business Research Management Center is interested in research of this type since it has a specific project in this area. The title of the project is "Use of Energy Efficiency Evaluation in Source Determination". The stated task of the project is to "determine the energy efficiency criteria which can be applied to the procurement and scheduling process . . ." The team assigned to this project turned in their final report last year (Rawl, et al, 1979).

This review will look at each chapter and review the material in the chapter with respect to the overall objectives set forth in Chapter I. The objectives were to identify and examine the energy costs incurred by producing and by using products, and to review cost models that aid in the consideration of these energy costs in the production process and the acquisition process. The methodology for the analysis is a literature review, a taxonomy, and examples of the models.

Chapter II, A Review of the Literature, examines a few of the thoughts in the field on the consideration of energy in the source selection or acquisition process. The need for formalized study in this area is established in the beginning of the chapter. Although many sources give reasons for this need, only one is quoted (Tether) primarily because the author's statement was representative of all of the literature in this area. The chapter then examines the Air Force policies concerning the consideration of energy effectiveness in the acquisition process. The source is the AF Regulation 70-15. A short study on establishing evaluation criteria is also presented, primarily to show where energy evaluation criteria can fit in to the process.

Chapter II also presents a section concerning some of the thoughts in the literature about conservation of energy. The ideas presented include the establishment of energy standards and the use of value incentive clauses to encourage the producer to initiate plant-wide energy conservation measures.

Chapter III, Taxonomy of Energy Costs, presents a cost breakdown structure with respect to the economic costs associated with energy consumption. The first section examines the energy costs accrued by the producer from the manufacturing plant and processes. The analysis divides the costs into two main categories: (1) research and developement costs and (2) production and construction costs. Under each category, specific cost areas are discussed with respect to energy costs. Figure 1 and Figure 2 summarize this analysis. The second section of the chapter examines energy costs accrued by the user of the product acquired from the producer. Figure 3 and 4 summarize this analysis.

Chapter IV, Models for Considering Energy Costs, provides examples of available models for both the producer of the product and the user of the product. The first section of this chapter presents information about the various computer models available for use by the producer to analyze the energy consumption of his plant. Details about each program are presented along with details about how to get further information on each program. The next section examines transportation models and how they can be used by the producer to minimize energy expenditures from the transportation functions of his business. Models to aid the producer in optimizing the manufacturing process are also presented. These models are throughout the literature in this area, and are not difficult to implement. Finally, the chapter contains examples of models that can be used directly in the source selection process to aid in making the final product choice.

This thesis, An Examination of Decision Analysis Models for Energy Consideration in Source Selection, is a groundwork project from which other studies may build. The taxonomy of the energy costs found in industry can provide a basis for any work concerning energy costs in the Air Force. The sections that present various models can also be used for designing unique models. However, as the warning at the beginning of this chapter indicates, models should not be totally relied upon as the basis for a management decision. Models are limited in scope and ability by design, and the result of a model should provide an information source input to a decision and not the decision itself. That should be left up to the discretion of the manager. For energy considerations in source selection, the Source Selection Authority might consider using models as tools and not as surrogates for the rational thought processes of decision making. Therefore, it is recommended by the author that any model that the SSA might use to make a decision between products be as simple in nature as is practical and be used mainly as a screening device.

Further study in this area can be directed toward a more specific examination of the techniques available to the SSA or purchasing officer to aid in the acquisition decision. A thesis that compares various cost models based upon criteria concerning their ability to aid the decision maker in the acquisition decision would be useful work. Such a work would be along the lines of the Allan and Transmeier thesis, "A Review of the Methods for Passive Solar Systems Analysis." This type of guidance can be very beneficial to the Air Force, and can help insure a less than gloomy energy future.

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